

## HIGH POWER SEMICONDUCTOR LASER DIODE

The present invention is directed to a semiconductor laser diode having increased output power, and, more particularly, to a high power semiconductor laser diode having an enlarged waveguide.

### BACKGROUND OF THE INVENTION

A semiconductor laser diode basically comprises a body of a semiconductor material or materials having a waveguide region and a clad region on each side of the waveguide region. Within the waveguide region is a region, such as a quantum well region, in which photons are generated when the diode is properly biased by and electrical current. The clad regions are doped to be of opposite conductivity type and are of a material having a lower refractive index than the material of the waveguide region so as to attempt to confine the photons to the waveguide region.

In the design of laser diodes heretofore made and known to those skilled in the art as being of optimum design, the thickness of the waveguide region was limited in extent, usually to be in the order of 0.2 to 0.3 micrometers ( $\mu\text{m}$ ), so as to achieve a minimization of the threshold current. To achieve the minimization of the threshold current, a substantial overlapping of the optical mode generated in the waveguide region into the adjacent doped regions, such as the clad regions, occurred. Although a major portion of the optical mode generated in the waveguide region remains and travels along the waveguide region, a portion of the optical mode at each end thereof extends into, i.e., overlaps into, the regions of the diode adjacent the waveguide region. This typically results in undesirable optical propagation losses. The propagation loss in a clad region contributes to the propagation loss of the lasing mode to the extent of the propagation loss of said clad region multiplied by the overlap factor of the clad region by the lasing mode. The overlap factor of a clad region is the proportion of photons which are carried in the clad region. Throughout this specification the term "propagation loss" means the propagation loss of the lasing mode. Thus, the overall efficiency of the device is reduced, thereby limiting directly and indirectly the output power capability of the device. Another constant on typical semiconductor laser diodes heretofore made has been the length of the diode, i.e., the distance between its ends. The longer the laser diode, the lower the thermal and electrical resistance of the diode and therefore, in general, the larger the output power. However, because of the lower efficiency resulting from the propagation losses, the length of the laser diode has been limited.

High efficiency, high power lasers have long been pursued for such applications as optical pumping of solid state and fiber laser, direct material processing, printing, communications, sensing, etc. Therefore, it would be desirable to improve the efficiency and reduce the losses of such laser diodes so as to increase the output power of the devices.

### SUMMARY OF THE INVENTION

A semiconductor laser diode formed of a body of a semiconductor material. The body includes a waveguide region which is not intentionally doped and having therein means for generating photons. A separate clad region is on each side of the waveguide region and the clad regions are at least partially doped to be of opposite conductivity types. The thickness of the waveguide region and the composition

of the waveguide and clad regions are such that an overlapping of the optical mode generating in the waveguide region into the clad regions is no greater than about 5%.

### BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of a basic semiconductor laser diode which incorporates the present invention;

FIG. 2 is a representation of a separate confinement heterostructure (SCH) laser diode which can incorporate the present invention;

FIG. 3 is a representation of a stepped SCH laser diode which can incorporate the present invention; and

FIG. 4 is a representation of a GRIN-SCH form of laser diode which can incorporate the present invention.

### DETAILED DESCRIPTION

Referring initially to FIG. 1, a semiconductor laser diode which incorporates the present invention is generally designated as 10. Laser diode 10 comprises a body 12 of a semiconductor material or materials having a bottom surface 14, top surface 16, end surfaces 18 and side surfaces 20. The body 12 includes a waveguide region 22 extending thereacross. Within the waveguide region 22 is an active region 24 in which photons are generated when an appropriate electrical bias is placed across the diode 10. The active region 24 may be of any structure well known in the laser diode art which is capable of generating photons. Preferably, the active region 24 comprises one or more quantum wells. The waveguide region 22 includes layers 26 on each side of the active region 24 which are of undoped semiconductor material having a doping level of no greater than about  $5 \times 10^{16}$  atoms/cm<sup>3</sup>.

On each side of the waveguide region 22 is a separate clad region 28 and 30. The clad regions 28 and 30 are layers of a semiconductor material of a composition which has a lower refractive index than the materials of the layers 26 of the waveguide region 22. Also, the clad regions 28 and 30 are at least partially doped to be of opposite conductivity type. The doping level in the clad regions 28 and 30 are typically between about  $5 \times 10^{17}$ /cm<sup>3</sup> and  $2 \times 10^{19}$ /cm<sup>3</sup>. For example, the clad region 28 between the waveguide region 22 and the top surface 16 of the body 12 may be of P-type conductivity and the clad region 30 between the waveguide region 22 and the bottom surface 14 of the body 12 may be of N-type conductivity.

A contact layer 32 of a conductive material, such as a metal, is on and in ohmic contact with the P-type conductivity clad region 28. The contact layer 32 is in the form of a strip which extends between the end surfaces 18 of the body 12 and is narrower than the width of the body 12, i.e., the distance between the side surfaces 20 of the body 12. A contact layer 34 of a conductive material, such as a metal, is on and in ohmic contact with the N-type conductivity clad region 30. The contact layer 34 extends across the entire area of the bottom surface 14 of the body 12.

In the laser diode 10 to achieve the higher efficiency and thus the higher output power, the thickness of the waveguide region 22 and the composition of the waveguide region 22 and the clad regions 28 and 30 must be such that the optical mode generated by the active region 24 does not overlap from the waveguide region 22 into the clad regions 28 and 30 by more than 5%, and preferably by not more than 2%. However, the amount of overlap of the photons into the clad regions 28 and 30 need not be less than 1%. This means that the amount of the optical mode, which is mainly in the

waveguide region 22, that extends into (overlaps) the clad regions 28 and 30 is no greater than about 5% of the total optical mode. To achieve this, the thickness of the waveguide region should be at least 500 nanometers (nm) and the composition of the waveguide region 22 and the clad regions 28 and 30 should be such that the refractive index of the regions provides the confinement of the optical mode in the waveguide region 22 to the extent that the overlap of the optical mode into the clad regions 28 and 30 is not greater than 5%. The various regions of the body 12 may be made of any of the well known semiconductor materials used for making laser diode, such as but not limited to gallium arsenide, aluminum gallium arsenide, indium phosphide, indium gallium arsenide and such quaternary materials as indium, gallium arsenide phosphide. However, the materials used for the various regions must have refractive indices which provide the desired confinement of the optical mode. The clad regions 28 and 30 may be doped uniformly throughout their thickness or may be graded with little or no doping at their junction with the waveguide region 22 and the heaviest doping at the respective surface of the body 12.

Referring to FIG. 2, there is schematically shown one form 36 of a laser diode in accordance with the present invention. Laser diode 36 is similar in structure to the laser diode 10 shown in FIG. 1 and includes a waveguide region 38 having therein a single quantum well region 40 of undoped  $\text{In}_{20}\text{Ga}_{80}\text{As}$  and a separate confinement layer 42 of undoped  $\text{Al}_{30}\text{Ga}_{70}\text{As}$  on each side of the quantum well region 40. A P-type conductivity clad region 44 is on one side of the waveguide region 38 and an N-type conductivity clad region 46 is on the other side of the waveguide region 38. Each of the clad regions 44 and 46 are of  $\text{Al}_{60}\text{Ga}_{40}\text{As}$ . Although the laser diode 36 is shown as having only a single quantum well region 40, it may have a plurality of quantum well regions which are spaced apart by barrier regions as is well known in the laser diode art.

Referring to FIG. 3, another form of the laser diode in accordance with the present invention is schematically shown and generally designated 48. Laser diode 48 comprises a waveguide region 50 having therein three quantum well regions 52 of  $\text{InGaAsP}$  and spaced apart by barrier regions 54 of  $\text{InGaAsP}$  having a bandgap of 1.0 eV. At each side of the quantum well regions 52 are inner confinement layers 56 also of  $\text{InGaAsP}$  having a bandgap of 1.0 eV. Adjacent each of the inner confinement layers 56 is an outer confinement layer 58 of  $\text{InGaAsP}$  having a bandgap of 1.13 eV. Adjacent the outer confinement layers 58 are clad regions 60 and 62 of  $\text{InP}$  which are doped N-type and P-type respectively. The clad regions 60 and 62 are doped to a level of between  $5 \times 10^{17}/\text{cm}^3$  and  $2 \times 10^{19}/\text{cm}^3$ . The N-type clad region 60 is doped uniformly throughout its thickness, but the P-type clad region 62 may have a graded doping from a lowest level at the interface with the outer confinement layer 58 to a highest level at its surface.

Laser diodes 48 were made with the quantum well regions 52 being of a thickness of 4.5 nm, and the barrier regions being of a thickness of 16 nm. The inner confinement layers 56 were of a thickness of 30 nm. In one laser diode 48 the outer confinement layers were of a thickness of 300 nm. and in another laser diode 48 the outer confinement layers were of a thickness of 600 nm. This provided laser diodes 48 in which the total thickness of the waveguide regions 50 were 0.7 and 1.3  $\mu\text{m}$  respectively. When tested the laser diodes were found to have an increasing efficiency with increased thickness. The laser diode 48 having the 1.3  $\mu\text{m}$  thick waveguide region 50 had an efficiency 1.3 time higher and threshold currents 10–20% lower than the laser diode 48

having the 0.7 thick waveguide region 50. Output powers of 4.6 W, CW and 6.8 W, quasi-CW at wavelengths of 1.42 to 1.5  $\mu\text{m}$  were obtained from these laser diodes 48.

Referring to FIG. 4, still another form of a laser diode incorporating the present invention is schematically shown and is generally designated as 62. Laser diode 62 has a waveguide region 64 in which is a quantum well region 66. On each side of the quantum well region 66 is a confinement region 68. Clad regions 70 and 72 of N-type and P-type conductivity are at opposite sides of the waveguide region 64. In the laser diode 62 the confinement regions 68 are of a material whose composition is graded to provided a graded band gap. Although the laser diode 62 is shown with a single quantum well region 66 it can have a multiple number of quantum well regions spaced by barrier regions, such as shown in the laser diode 48 shown in FIG. 3.

Thus there is provided by the present invention a laser diode having a thicker waveguide region, at least 500 nm in thickness, and which has a small overlap of the optical mode into the clad regions, no greater than about 5%. Since the waveguide region is not intentionally doped, it has a small thermal and electrical resistance, so that the optical mode can travel through the waveguide region with little optical loss. Since only a small portion of the optical mode overlaps into the more highly doped clad regions, which have a greater thermal and electrical resistance, there is only a small optical loss in the clad regions. Since the optical losses are lower, the device has a greater efficiency and a greater optical power output. In addition, the laser diode of the present invention provides a larger area spot size of the emitted beam. The larger spot size reduces the damage to the emitting surface of the laser diode so as to increase the operating lifetime of the laser diode. In addition, the laser diode of the present invention can be made longer, i.e., lengths of 2 millimeters or longer. Since there is lower losses in the laser diode it can be made longer to provide greater power output. Furthermore, although the laser diode shown and described is of a separate confinement quantum well structure, it should be understood that the present invention can be used in laser diodes of any of the well known structure, such as lateral waveguiding ridge structures, buried structures, gain-guided structures, distributed feedback structures, distributed Bragg reflector structures, etc.

What is claimed is:

1. A semiconductor laser diode comprising:

a body of a semiconductor material having therein a waveguide region which is not intentionally doped and which is of a material which substantially confines photons therein and allows the flow of photons therealong;

means within the waveguide region for generating an optical mode of photons; and

a clad region on each side of the waveguide region, the clad regions being at least partially doped to be of opposite conductivity type;

said photon generating means being thinner than the thickness of the waveguide region and being spaced from the clad layers;

the thickness of the waveguide region and the composition of the waveguide and clad regions being such that an overlapping of the optical mode generated in the waveguide region into the clad regions is not greater than about 5%.

2. The semiconductor laser diode of claim 1 in which the waveguide region is of a thickness of at least 500 nanometers.